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TESTS ON THERMOELECTRIC SEMICONDUCTOR ELEMENTS

OF THE U.S.S.R.

[redacted] Tests on the T3gK2-2 Kerosene Lamp
Electric Power Supply for Radio Receivers

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This is the first such report and covers a thermoelectric generator of electrical power for a small radio receiver in which the source of energy is derived from a kerosene lamp. [redacted] ~~these~~ This ~~reports~~ report will only cover operational and technical tests.

The lamp generator is not an important item for American exploitation, and in fact, is a somewhat old development in the U.S.S.R. too. However, a technical report on it serves the purpose of familiarizing prospective clients with the characteristics of semiconductor thermoelectric elements, which are of more general economic importance.

INTRODUCTION

A type T3gK2-2 thermoelectric generator kerosene lamp was procured at the GUM Department Store in Moscow, U.S.S.R., during a visit in September 1958. A photograph of the generator is shown as Fig. 1. It consists of a kerosene lamp bowl and wick, a lamp globe, the finned thermoelectric generator proper, and a metallic chimney to carry off the hot gas combustion products.

The lamp globe confines and channels the combustion products through a central cylindrical cored "heat source" for the generator. After passage through this heat core, the combustion products pass through the chimney.

A top view photograph of the generator is shown in Fig. 2.

A cut-away, approximate artist's visualization of the structure is shown as Fig. 3. One may note that the basic structure is a heat diffusion core which acts as a high temperature source for a thermopile of semiconductor elements; the thermopile itself; a composite structure of fins which creates the low "ambient" temperature sink; and two annular plate structures required for mechanical load bearing. The two plates act as heat shunts, and an attempt is made to minimize their shunt loss. The thermopile appears to be grouped as fourteen sets of bars with one pair of aluminum fins per set. Asbestos and mica are used for heat and electrical insulation respectively.

A. F. Ioffe, Director of the Institute for Semiconductors of the U.S.S.R. Academy of Sciences, makes the following statements about thermoelectric generators in his book, "Semiconductor Thermoelements and Thermoelectric Cooling," (Infosearch Ltd., 1957):

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"....shows......a kerosene lamp manufactured in the U.S.S.R....... The inside of the tube is heated by the hot combustion gases and the outside is cooled with the aid of a set of radiators. The temperature difference created in this way amounts to 250-300° C.; this gives a few watts of electric energy for feeding a radio receiver set.......shows a more powerful battery rated at 15-20 watts which is mounted on a kerosene burner and used to feed radio transmitters used in agricultural work. Thermoelectric batteries are used in tractors in place of dynamos.

More powerful generators with capacities of 200 and 500 watts are also being manufactured. These generators use all types of fuels (firewood or petrol) and are intended for the North. A furnace generating 200 watts consumes approximately 2 kilograms of firewood per hour."

It must be clear from this and other material that what is being indicated is thermoelectric conversion from heat to electricity at levels of at most a few per cent. Of all such developments, the lamp being reported on here is the oldest and crudest production example. We have taken the trouble to characterize its performance because such characterisation is a typical introduction to this class of such devices.

The lamp is thus basically a low-efficiency generator of electric power for a radio. In particular, the instruction booklet furnished with the lamp indicates the terminal outputs shown in Fig. 4. The lamp furnishes an independent A supply of 1.2 volts; and a second supply of 99 volts, tapped to furnish a B+ supply of 90 volts; and a negative C bias of 9 volts.

Normal operation of this particular lamp using the kerosene heat supply, turned up full, provides 89 volts B+ supply, 8.9 volts C supply, 2.6 volts A supply for no external load condition. Experimental conditions were chosen to approximately match this situation but to not exceed it seriously. No determination of maximum safe output was made, nor of the factors on which this limit depends.

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EXPERIMENTAL MEASURING TECHNIQUE

Useful evaluation of the thermoelectric converter requires calorimetric techniques; it was preferable that it be made using an electric energy input, rather than the kerosene heat of combustion input. Thus input heating was accomplished by the use of six quartz tube laboratory heaters (nichrome resistance - 125 watt nominal rating) inserted into the channels of the heat diffuser core and packed in place with 80 mesh aluminum granular powder. The heaters were parallel fed from an autotransformer. The power was monitored by a wattmeter. Some of the details of the test setup may be noted by reference to Fig. 6.

The system as a whole was isolated as follows: The heat core was axially insulated by machined blocks of asbestos board, the lower set of blocks serving as the support stand for the generator. The cold sink was cooled by series-connected, water-cooled copper tubes installed in the fin clamp channels. The 1/8-inch OD copper tube lay in seven "U"-shaped sections, one leg of which was threaded through one cold junction clamp with low melting solder (47 °C. m.p.) cast into place around it. Appropriately-sized plastic tubing served to feed and connect the copper tube sections. Water for cooling was obtained by regulating the flow rate and temperature of water from the cold tap supply. The water was warmed to very nearly room temperature. Mittens of asbestos paper were slipped over the cooling fins so as to minimize heat exchange. The cold junction was operated close to room temperature, also, to keep heat exchange low. Cooling water coming out of the generator was run into a measuring graduate to determine the flow rate and temperature.

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Nine copper-constantan (28 gauge) thermocouples connected to an ice bath zero reference were used to measure generator heat source and cold sink temperatures. Cold sink temperatures were measured against the aluminum cooling fins, with the thermocouple buried in the cast, low melting alloy, at the water-cooling inlet, midway fin, and outlet fin. Heat source temperatures were obtained from thermocouples pressed into holes drilled into the heat diffusion core, located as shown in Fig. 5.

Figure 6 is a photograph of the test setup.

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a) Effective thermal conductance of the generator

It is of utility to characterise the effective thermal conductance of the generator. The data shown in Table 1 permits this estimate. In Table 1 are the input wattage, the lowest temperature measured in the heat core, and the highest temperature measured in the root of the fins. These measurements permit one to assess the nominal conductance that might be charged to the thermopile (i.e., thermoelements plus thermal resistance of electrical resistance plus a small conducting segment plus resistance into the fins, minus shunting resistance).

TABLE 1

Nominal Thermal Conductance of Generator

Input Power Nominal watts	"True" watts	Temperature at Heat Source °C.	Temperature at Cold Sink °C.	Temperature Drop °C.	Conductance watts/°C.
350	325	306	33.0	273.0	1.19
300	279	254	31.5	222.5	1.25
200	186	184	28.0	156.0	1.19
100	93	97	20.5	76.5	1.22
				Average	1.21

From its nominal cylindrical dimensions, the conductivity, k, of an equivalent homogeneous cylinder would be

$$k = \frac{P}{\Delta T} \ln \frac{d_1/d_2}{2\pi h}$$

k = = conductivity
d_1 = outer diameter (= 4 3/4 inches)
d_2 = inner diameter (= 2 inches)
h = cylinder height (= 5 inches)

k = 0.026 watts/cm. °C.

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It may be noted that this conductivity lies in the range between the good thermal insulators and the good thermal conductors; i.e., in a range that may be associated with the semiconductors.

b) Output circuit characteristics

With a constant input heating power maintained, the voltage-current-external added resistance characteristic was measured at each of four input powers (and therefore corresponding temperature drops). The external measuring circuit is shown in Fig. 7. The data thus obtained are shown in Table 2.

Since the measurements were made on a somewhat crude basis, it was desirable that measured values be analytically refined to some extent.

(A) Plate supply circuit

Independent terminal voltage, current, and external added resistance measurements were made. Their self-consistency was first checked by noting the self-consistency with which one could estimate the voltmeter resistance, denoted as R_V, by the relation:

$$1/R_V = I/V - 1/R_X$$

In column 6, are the estimates of $1/R_V$. It may be noted that a reasonable estimate of about 0.000019 $ohms^{-1}$ is obtained (with an average deviation of about 5 per cent). This corresponds to about 52,000 ohms (or about 500 ohms per volt), which checks the nominal stated and measured characteristics of the meter.

TABLE 2

A. Plate and bias circuits in series

EXPERIMENT NO. I - 350 watt input

R_x	V	I	I/V	$1/R_x$	$1/R_v$	1/R	V	I
						Corrected Values		
ohms	volts	amps					volts	amps
150	7.5	.053	-	.00667	-	.0069	7.94	.053
200	10	.0495	-	.005	-	.00502	9.85	.0495
400	17.8	.045	-	.0025	-	.00252	17.8	.045
800	29.8	.0378	.00127	.00125	.00002	.00127	29.8	.0378
1000	34.3	.035	.00102	.00100	.00002	.00102	34.3	.035
1200	38.5	.0328	.000851	.000833	.000018	.000852	38.5	.0328
1400	42	.0308	.000734	.000715	.000019	.000734	42.0	.0308
1500	43.8	.0298	.000681	.000667	.000014	.000686	43.6	.0299
1600	45	.029	.000645	.000625	.000020	.000644	45.0	.0290
1700	46.5	.0281	.000604	.000588	.000016	.000607	46.4	.02815
1800	48.1	.0273	.000568	.000555	.000013	.000574	47.8	.0274
1900	49	.0268	.000547	.000526	.000021	.000545	49.1	.0267
2000	51	.0261	.000520	.000500	.000020	.000519	50.6	.0262
3000	60	.0211	.000352	.000333	.000019	.000352	60	.0211
4000	66	.0178	.000270	.000250	.000020	.000269	66.0	.0178
6000	73	.0138	.000189	.000167	.000022	.000186	73.5	.0137
8000	77.8	.0112	.000144	.000125	.000019	.000144	77.8	.0112
10,000	81	.0099	.000122	.000100	.000022	.000119	82	.0098
-	94	.0021	.0000224	-	-	.000022	94	.0021

EXPERIMENT NO. II - 300 watt input

400	14	.0360	-	.0025	-	.00252	14.2	.0358
800	23.5	.0305	-	.00125	-	.00127	23.8	.0302
1000	27.5	.0282	-	.001	-	.00102	27.6	.0282
1200	30.5	.0265	-	.000833	-	.000852	30.8	.0262
1400	33.8	.0248	.000733	.000714	.000019	.000734	33.8	.0248
1500	34.8	.0240	.000690	.000667	.000023	.000686	34.9	.0239
1600	36.1	.0234	.000648	.000625	.000023	.000644	36.2	.0233
1700	37.2	.0228	.000612	.000588	.000024	.000607	37.3	.0227
1800	38.8	.0221	.000570	.000555	.000015	.000574	38.7	.0222
1900	40.0	.0216	.000539	.000526	.000013	.000545	39.8	.0217
2000	40.6	.0212	.000522	.0005	.000022	.000519	40.6	.0211
3000	48.5	.0171	.000353	.000333	.000020	.000352	48.5	.0171
4000	53.5	.0145	.000271	.000250	.000021	.000269	53.6	.0144
6000	59	.0112	.000190	.000167	.000023	.000186	59.5	.0111
8000	63	.0092	.000146	.000125	.000021	.000144	63.5	.00915
10,000	65.1	.008	.000123	.000100	.000021	.000119	65.1	.0078
-	76.1	.00175	-	-	-	.000023	76.1	.00175

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TABLE 2

A. Plate and bias circuits in series

EXPERIMENT NO. III - 200 watt input

R_x ohms	V volts	I amps	I/V	$1/R_x$	$1/R_v$	1/R	V (Corrected Values) volts	I (Corrected Values) amps
300	7.2	.0249	-	.00333	-	.00335	7.4	.0247
400	9.5	.0238	-	.00250	-	.00252	9.5	.0238
800	16	.0203	-	.00125	-	.00127	16.0	.0203
1000	19.5	.0190	-	.00100	-	.00102	19.0	.0194
1200	22	.0178	-	.000833	-	.000852	21.5	.0183
1400	24	.0168	-	.000715	-	.000734	23.5	.0172
1500	25.1	.0164	-	.000667	-	.000686	24.5	.0168
1600	26.0	.0160	-	.000625	-	.000644	25.5	.0164
1700	26.8	.0155	-	.000588	-	.000607	26.2	.0159
1800	27.1	.0151	-	.000555	-	.000574	26.7	.0153
1900	27.8	.0148	-	.000526	-	.000545	27.5	.0150
2000	28.8	.0143	-	.000500	-	.000519	28.1	.0146
3000	34	.0116	-	.000333	-	.000352	33.5	.0118
4000	37.	.0099	.000267	.000250	.000017	.000269	36.8	.0099
6000	42	.0076	.000181	.000167	.000014	.000186	41.5	.0077
8000	44	.0063	.000143	.000125	.000018	.000144	43.8	.0063
10,000	45	.0055	.000122	.000100	.000022	.000119	45.6	.00545
-	53.5	.0010	-	-	-	.000019	53.5	.0010

EXPERIMENT NO. IV - 100 watt input

R_x ohms	V volts	I amps	I/V	$1/R_x$	$1/R_v$	1/R	V (Corrected Values) volts	I (Corrected Values) amps
300	3.0	.0121	-	.00333	-	.00335	3.6	.0121
700	6.5	.0110	-	.00143	-	.00145	7.5	.0109
1000	8.5	.0094	-	.00100	-	.00102	9.0	.0092
1500	11.0	.0080	-	.000667	-	.000686	11.5	.0079
2000	13.0	.0070	-	.000500	-	.000519	13.3	.0069
3000	15.5	.0055	.000354	.000333	.000021	.000352	15.5	.0055
4000	17.0	.0046	.000269	.000250	.000019	.000269	17.0	.0046
5000	18.1	.0039	.000215	.000200	.000015	.000220	18.0	.0039
6000	19.0	.0035	.000182	.000167	.000015	.000186	19.0	.0035
7000	19.5	.0031	.000156	.000143	.000013	.000162	19.3	.0031
8000	20.0	.0026	-	.000125	-	.000144	20.0	.0027
10,000	20.9	.0023	-	.000100	-	.000119	20.6	.0024
20,000	21.9	.0012	-	.000050	-	.000069	21.6	.0015
-	24.5	.0001	-	-	-	.000019	24.5	.0005
					Average 0.000019			

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TABLE 2

B. Filament circuit

EXPERIMENT NO. I - 350 watt input

R_x	V	I	I/V	R_w	R	V	I
					Corrected Values		
ohms	volts	amps	mhos	ohms	ohms	volts	amps
0	0.45	.74	1.648	.61	.48	.37	.77
1	0.85	.578	.680	.47	1.48	.85	.575
2	1.18	.470	.398	.52	2.48	1.17	.472
3	1.35	.400	.2968	.40	3.46	1.38	.398
4	1.51	.349	.2312	.37	4.43	1.53	.345
6	1.72	.275	.160	.34	6.40	1.74	.272
8	1.85	.220	.119	.55	8.38	1.85	.221
9	1.90	.210	.1106	.21	9.32	1.93	.207
10	1.95	.190	.0974	.50	10.27	1.95	.190
30	2.25	.080	.0355	-	28.76	2.27	.0794
50	2.32	.055	.0237	-	45.8	2.33	.051
100	2.38	.030	.0126	-	83.4	2.38	.0286
∞	2.42	-	-	-	c. 510	2.42	.00474

EXPERIMENT NO. II - 300 watt input

0	.38	.58	1.527	.65	.48	.29	.61
1	.72	.460	.639	.57	1.48	.69	.467
2	.95	.358	.377	.67	2.48	.92	.370
3	1.15	.295	.2566	.92	3.46	1.11	.318
4	1.21	.275	.2276	.44	4.43	1.22	.275
6	1.36	.216	.1588	.38	6.40	1.37	.214
8	1.48	.178	.1204	.45	8.38	1.485	.1775
9	1.52	.162	.1066	.56	9.32	1.51	.162
10	1.55	.155	.100	.20	10.27	1.56	.1515
30	1.81	.065	.0359	-	28.76	1.81	.063
50	1.85	.040	.0216	-	45.8	1.86	.0406
100	1.90	.022	.0116	-	83.4	1.91	.0229
∞	1.95	-	-	-	c. 510	1.95	.0038

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TABLE 2

B. Filament circuit

EXPERIMENT NO. III - 200 watt input

R_x	V	I	I/V	R_w	R	V	I
					Corrected Values		
ohms	volts	amps	mhos	ohms	ohms	volts	amps
0	.25	.408	1.633	.612	.48	.20	.414
1	.50	.320	.64	.57	1.48	.48	.324
2	.68	.240	.354	.841	2.48	.62	.25
3	.75	.21	.280	.575	3.46	.74	.214
4	.82	.19	.232	.595	4.43	.83	.188
6	.92	.15	.163	.21	6.40	.94	.147
8	1.00	.124	.124	.20	8.38	1.02	.122
9	1.05	.11	.105	.71	9.32	1.04	.112
10	1.05	.108	.103	-	10.27	1.08	.105
30	1.21	.04	.0331	-	28.76	1.20	.0416
50	1.25	.03	.0240	-	45.8	1.26	.0275
100	1.30	.02	.0154	-	83.4	1.30	.0157
∞	1.32	-	-	-	c. 510	1.32	.00264

EXPERIMENT NO. IV - 100 watt input

0	.08	.162	2.025	.495	.48	.078	.162
1	.17	.128	.7525	.332	1.48	.19	.128
2	.25	.106	.424	.371	2.48	.26	.105
3	.29	.082	.2825	.546	3.46	.287	.083
7	.34	.047	.1382	.23	7.40	.345	.0466
10	.38	.0375	.102	-	10.27	.385	.0375
30	.5	.0168	.0336	-	28.76	.475	.0165
70	.47	.0073	.01555	-	61.9	.482	.0078
100	.50	.00545	.0109	-	83.4	.492	.0059
∞	.58	-	-	-	c. 510	.58	.00113

Average

0.48

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It is then possible to correct the measurements to specify the actual load placed on the generator, for:

$$\frac{1}{R} = \frac{1}{R_x} + \frac{1}{R_v}$$

The true external load, characterized as $1/R$, is given in column 7.

For columns 8 and 9, the errors in the measured values of V and I are split up between the voltage measurement and the current measurement to refine an estimate of V and I, on the basis of R, which is now taken as being correct. These refined estimates are shown in columns 8 and 9.

(B) Filament circuit

For the filament circuit measurement, wiring resistance may not be neglected. Thus it is necessary to use the relation:

$$\frac{I}{V} = \frac{1}{R_v} + \frac{1}{R_x + R_w}$$

Measurement of the meter resistance gave

R_v = 510 ohms

Thus R_w was estimated, for self-consistency, from

$$R_w = \frac{1}{I/V - 1/R_v} - R_x$$

In column 5 are the estimates of R_w. It may be noted that an approximate estimate of 0.48 ohms is obtained.

It is then possible to correct the measurements to specify the actual load placed on the generator, for

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$$R = \frac{R_v(R_x + R_w)}{R_v + R_A + R_x} = \frac{R_x + .48}{1 + R_x/510}$$

This is shown in column 6.

For columns 7 and 8, the errors in the measured values of V and I are split up between the voltage measurement and the current measurement to refine the estimate of V and I.

We may now crudely examine the voltage characteristic. Neglecting the ammeter resistance in the plate circuit measurement (or actually permitting it to exist as a systematic negligible error portion of the generator resistance),

$$V = E - Ir$$

V = terminal voltage (column 8)
I = source current
r = internal source resistance
E = generator voltage

or not neglecting the ammeter resistance

$$V = E - I\,(r + R_A)$$

The use we will put these equations to is as follows:

The generator voltage, E, and the source resistance, r, are at most smoothly varying functions of current, I, and source temperature (i.e. source power). In the limit, as current, I, approaches zero,

$$E \longrightarrow E_o$$

$$r \longrightarrow r_o$$

E_o = no load voltage (the thermal emf)
r_o = the no load resistance of the generator

One would expect, as an approximation, that both E and r would be constants very nearly. However, here we will basically only use the fact to estimate E_o and r_o. Fig. 8a and 8b are plots of V against I (columns 8 and 9) for the plate supply, and columns 7 and 8 for the filament supply).

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It may be noted that the characteristics are very, very nearly linear (i.e., the generator source characteristic is essentially only a "constant" thermoelectric voltage generator, in which the thermoelectric voltage depends only on the temperature difference; and over the temperature range tested, the internal resistance is "very nearly a constant").

However, it will be more conservative to only estimate from these data the no load thermal voltage and that no systematic variation in internal resistance with temperature over the temperature range tested could be found.

The net results of this analysis (of Fig. 8) is shown in Table 3 (making a correction of 0.21 ohms for the ammeter resistance in the filament supply internal resistance).

TABLE 3

No Load Generator Supply Characteristics

Nominal Input Power watts	Plate Voltage volts	Plate Resistance ohms	Filament Voltage volts	Filament Resistance ohms
350	97.8	1820	2.47	2.54
300	79.2	1820	1.97	2.54
200	55.2	1820	1.34	2.54
100	25.0	1820	.52	2.54

(8) Power input to generator

The power available to the generator could only be estimated from how much power could be measured calorimetrically at the output. This measurement was crude. The best rough estimate that could be made was that 7 per cent of the power was lost through other means (i.e., 93 per cent of the power was available to the generators).

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Furthermore it was not possible to estimate, except crudely, what the relative power division was between the two sources. From geometric factors, it appeared that the division might be approximately three-quarters to one-quarter between the plate and filament supplies. On a peak power basis, the division appeared to be 0.70 to 0.30. The latter figure will be adopted.

Thus the source power for the two sources is assumed to be:

TABLE 4

Total Power watts	Total Source Power watts	Power in Plate watts	Power in Filament watts
350	325	228	97
300	279	195	84
200	186	130	56
100	93	65	28

(D) Heat source temperature

Study of the various temperatures measured in the high temperature source core (See Fig. 6) suggested that the following tabulated values were the lowest temperatures found in the core.

TABLE 5

Total Power watts	"Source" Temperature °C.
350	306
300	254
200	184
100	97

These values should be interpreted as the lowest source temperature if the generator is to be charged with its electrical insulation from the source. In this case, the insulation consists of a thin layer of slightly crushed mica interposed between the core and the thermoelements. The performance of the thermoelements themselves are not estimated here.

(E) Cold sink temperature

The warmest temperature on the cold receiver side was found in the exit calorimetric cooling water. If it were assumed that a heat exchange in accordance with the logarithmic temperature difference took place, then the effective sink temperature (i.e., again an effective sink temperature beyond electrical insulation) could be estimated from three water temperatures (entrance, middle, exit) to be the values shown in Table 6. These temperatures were all very nearly the exit water temperature.

TABLE 6

Input Power watts	"Sink" Temperature °C.
350	33.0
300	31.5
200	28.0
100	20.5

THEORETICAL ANALYSIS OF GENERATOR PARAMETERS

Ioffe gives the following analysis of the generator: The heat power consumed from the source, Q, is given by

$$Q = Q_k + Q_1 - \tfrac{1}{2} I^2 r$$

Q_k = heat transferred by conduction
Q_1 = Peltier heat absorbed by the hot junction
$\tfrac{1}{2}I^2r$ = one-half the Joule heat produced in the thermoelement which is returned to the source

$$Q_k = K(T_1 - T_0)$$

K = thermal conductance
$T_1 - T_0$ = temperature difference, source to sink

$$Q_1 = \bar{a}IT_1$$

$\bar{a}$ = mean thermal emf coefficient
I = thermoelement current
T_1 = source temperature

$$I = \frac{\bar{a}(T_1 - T_0)}{R + r}$$

$\bar{a}(T_1 - T_0)$ = the thermoelectric emf
r = internal resistance of generator
R = external load connected to generator

Thus

$$Q = K(T_1 - T_0) + \frac{\bar{a}^2 T_1 (T_1 - T_0)}{R + r} - \tfrac{1}{2}\frac{\bar{a}^2 (T_1 - T_0)^2 r}{(R + r)^2}$$

The useful power, W, delivered by the generator is

$$W = I^2 R$$

$$W = \frac{\bar{a}^2 (T_1 - T_0) R}{(R + r)^2}$$

25X1

From these two relations for the source heat flux and delivered electric power, the terminal voltage-external resistance characteristic of the generator may be derived as follows:

$$W = V^2/R$$

V = terminal voltage

$$V = \bar{a} \frac{(T_1 - T_0) R}{R + r}$$

A critical first test of the adequacy of the Ioffe analysis may be had by testing the constancy of the thermoelectric potential with varying power. In Fig. 9, are plots of $1/V$ versus $1/R$ from the data in Table 2. Since

$$\left(1 + \frac{r}{R}\right) = \bar{a}(T_1 - T_0)\left(\frac{1}{V}\right)$$

linearity at constant temperature would demonstrate the constancy of r ($= r_0$) and the constancy of $\bar{a}$. Within the experimental error, the data indicate linearity. The important information to be gained from Fig. 8 is the indicated constancy. This is not too surprising because this lamp is a very low efficiency device (i.e., efficiencies of the order of 1-2%) so that there is little redistribution of temperature due to the passage of current. The most that could be concluded from the data is that over the temperature range tested (or mean temperature range tested), the resistance is a negligible function of temperature, and the thermoelectric potential nearly so.

The following refined data thus result from Fig. 8 and 9.

TABLE 7

Summary of Electric Characteristics

A. Plate Supply

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Nominal Total Power watts	Actual Power watts	Source Temp. °C.	Sink Temp. °C.	Mean Temp. °C.	Temp. Diff. °C.	Resistance ohms	Mean Thermoelectric Coefficient volts/°C.
350	228	306	33	170	273	1850 30	.360±.004
300	195	254	31.5	143	222.5	1850	.356±.004
200	130	184	28	106	156	1850	.348±.006
100	65	97	20.5	59	76.5	1850	.336±.006
						Average	.35 ±.015
		B. Filament Supply					
350	97	306	33	170	273	2.52 .03	.0089±.0001
300	84	254	31.5	143	222.5	2.52	.0088±.0001
200	56	184	28	106	156	2.52	.0086±.0002
100	28	97	20.5	59	76.5	2.52	.0075±.0007
						Average	.0084±.0006

If now we add the previous estimated conductance of 1.21 watts/°C. total or 0.85 watts/°C. for the plate supply (70%), and 0.36 watts/°C. for the filament supply (30%), it now becomes possible to estimate the figure of merit, Z_g, for the generator as a whole.

$$Z_g = \bar{a}^2/Kr$$

Strictly this does not permit assessment of the point value of Z_g, but only Z_{go}, where Z_{go} is defined by

$$Z_{go} = \mathcal{L}_{R \to \infty} \left(\frac{\bar{a}^2}{Kr} \right)$$

However, we have shown, to the accuracy measured, that $\bar{a}$ does not depend on current and is a small or negligible function of temperature, and that r is almost certainly a constant. Thus

$$Z_{go} = \frac{\bar{a}^2}{r_0} \mathcal{L}_{R \to \infty} \left(\frac{1}{K} \right)$$

25X1

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Now the first thermal conduction equation indicates that, for the no load condition ($R \rightarrow \infty$)

$$Q = K(T_1 - T_0)$$

i.e., this equation defines the limiting value of K required for measuring Z_g. However the thermal flux measurements made were under these no load conditions. Thus it is correct and valid to make use of the conductance figures 0.85 watts/°C. for the plate supply and 0.36 watts/°C. for the filament supply as proposed. The results for figure of merit are thus shown in Table 8.

TABLE 8

Figure of Merit

A. Plate Supply

Nominal Power watts	Mean Temp. °C.	Temp. Diff. °C.	Resistance ohms	Mean Thermoelectric Coefficient volts/°C.	Conductance watts/°C.	Figure of Merit °C.$^{-1}$
350	170	273.0	1850	.360	0.85	.083x10^{-3}
300	143	222.5	1850	.356	0.85	.081
200	106	156.0	1850	.348	0.85	.077
100	59	76.5	1850	.336	0.85	.072
				Average .350		.078x10^{-3}

B. Filament Supply

Nominal Power watts	Mean Temp. °C.	Temp. Diff. °C.	Resistance ohms	Mean Thermoelectric Coefficient volts/°C.	Conductance watts/°C.	Figure of Merit °C.$^{-1}$
350	170	273.0	2.52	.0089	0.36	.087x10^{-3}
300	143	222.5	2.52	.0088	0.36	.086
200	106	156.0	2.52	.0086	0.36	.082
100	59	76.5	2.52	.0075	0.36	.062
				Average .0084		.078x10^{-3}

25X1

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These data are shown in Fig. 10 as the figure of merit as a function of mean temperature. One may conclude from Fig. 10 that the figure of merit has a slight temperature dependence, falling within the band shown, or has no temperature dependence, falling within the larger uncertainty band shown (i.e., $0.078 \times 10^{-3} \pm 0.010 \times 10^{-3}\ {}^{\circ}C^{-1}$).

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DISCUSSION

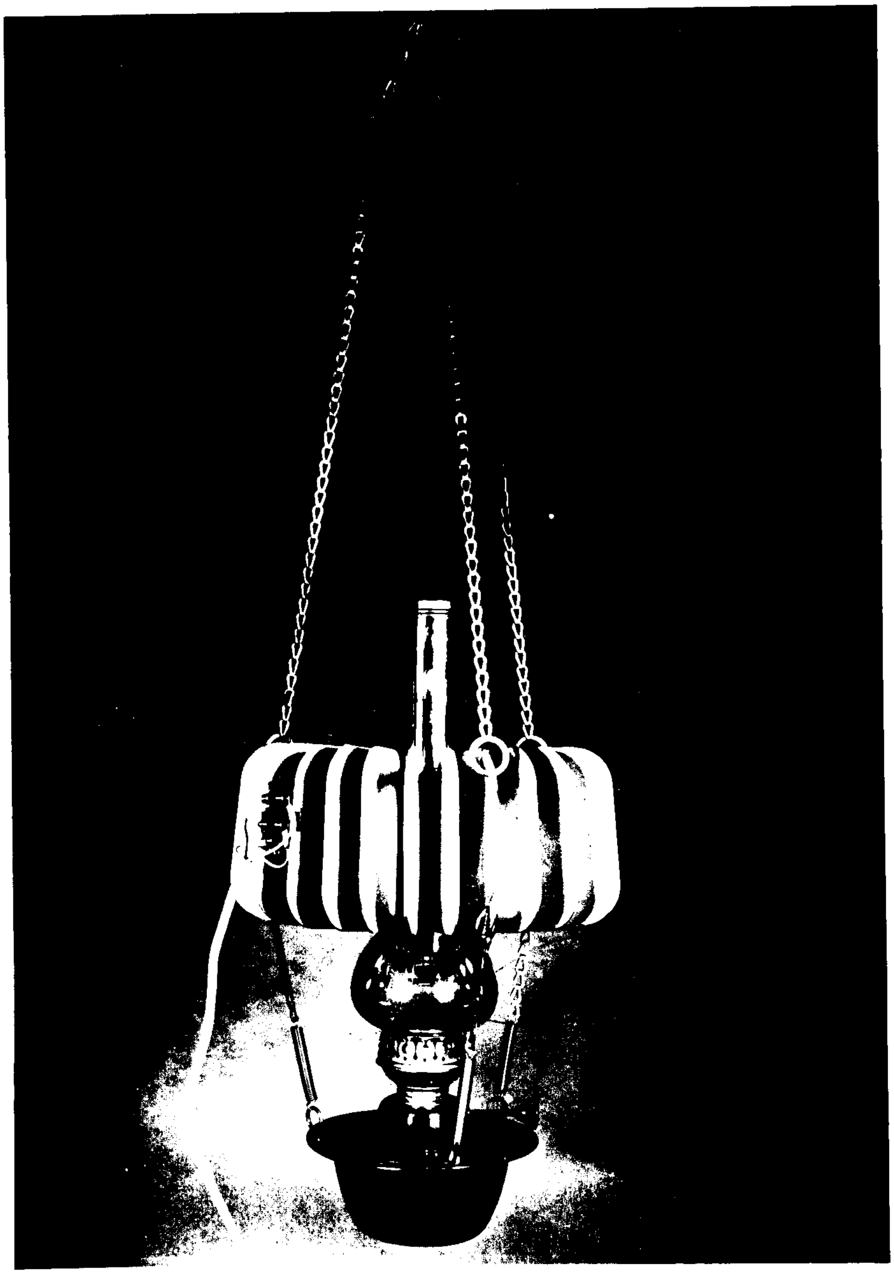
At first sight, this figure of merit may seem quite low (i.e., 0.1×10^{-3} $^{\circ}K^{-1}$), particularly compared to the large numbers currently reported on in research all over the world (2×10^{-3}, 3×10^{-3}, 3.5×10^{-3}, even $4\text{-}4.5 \times 10^{-3}$). To make the numbers more meaningful, we must note that the lower figure corresponds to an efficiency of the order of one or two per cent and represents the whole generator rather than the elements themselves; whereas the research figures correspond to efficiencies in the tens of per cent for the newest elements.

It is important that this lamp development now is approximately six years old already; production knowhow is at least that old. [redacted]

4/21/59

[redacted]

April 1959



T3gK2-2

THERMOELECTRIC GENERATOR

25X1

FIG. 1

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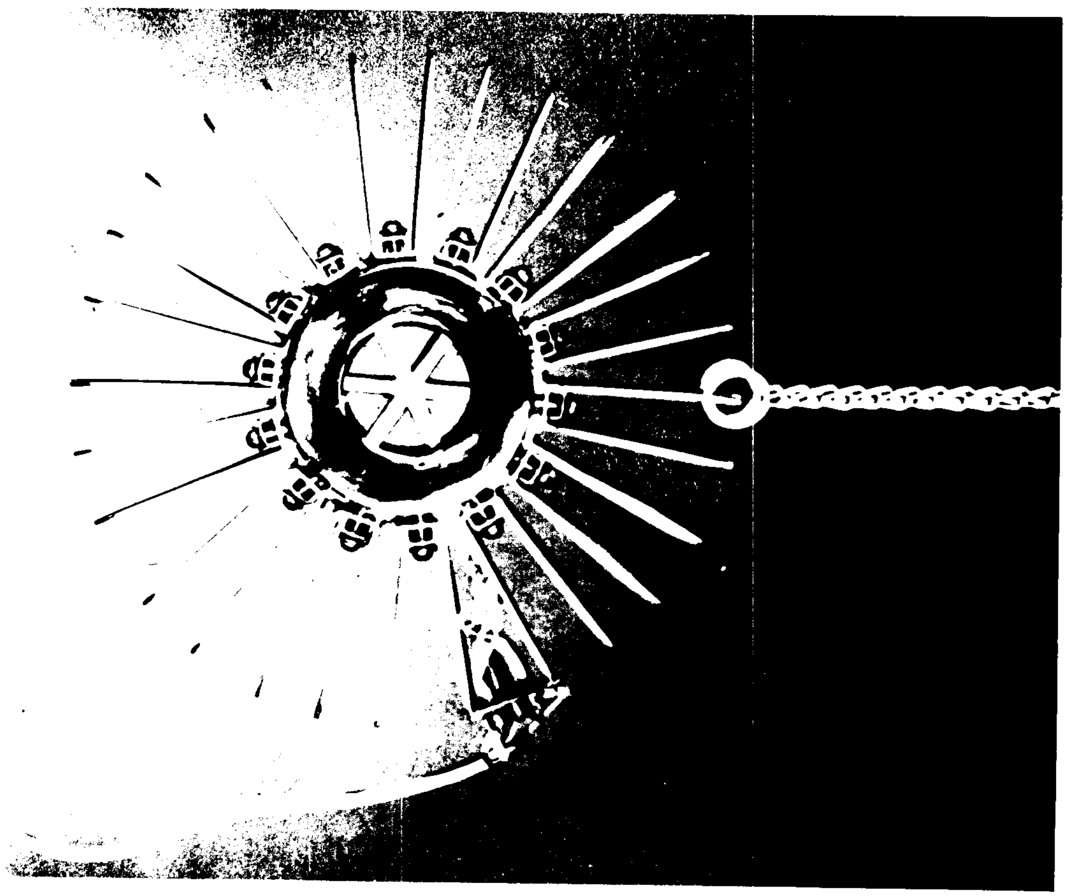

TOP VIEW OF T3gK2-2

Showing fin clamping system at cold junctions,

aluminum heat-spreading spider in hot zone,

and terminal connection

25X1

FIG. 2

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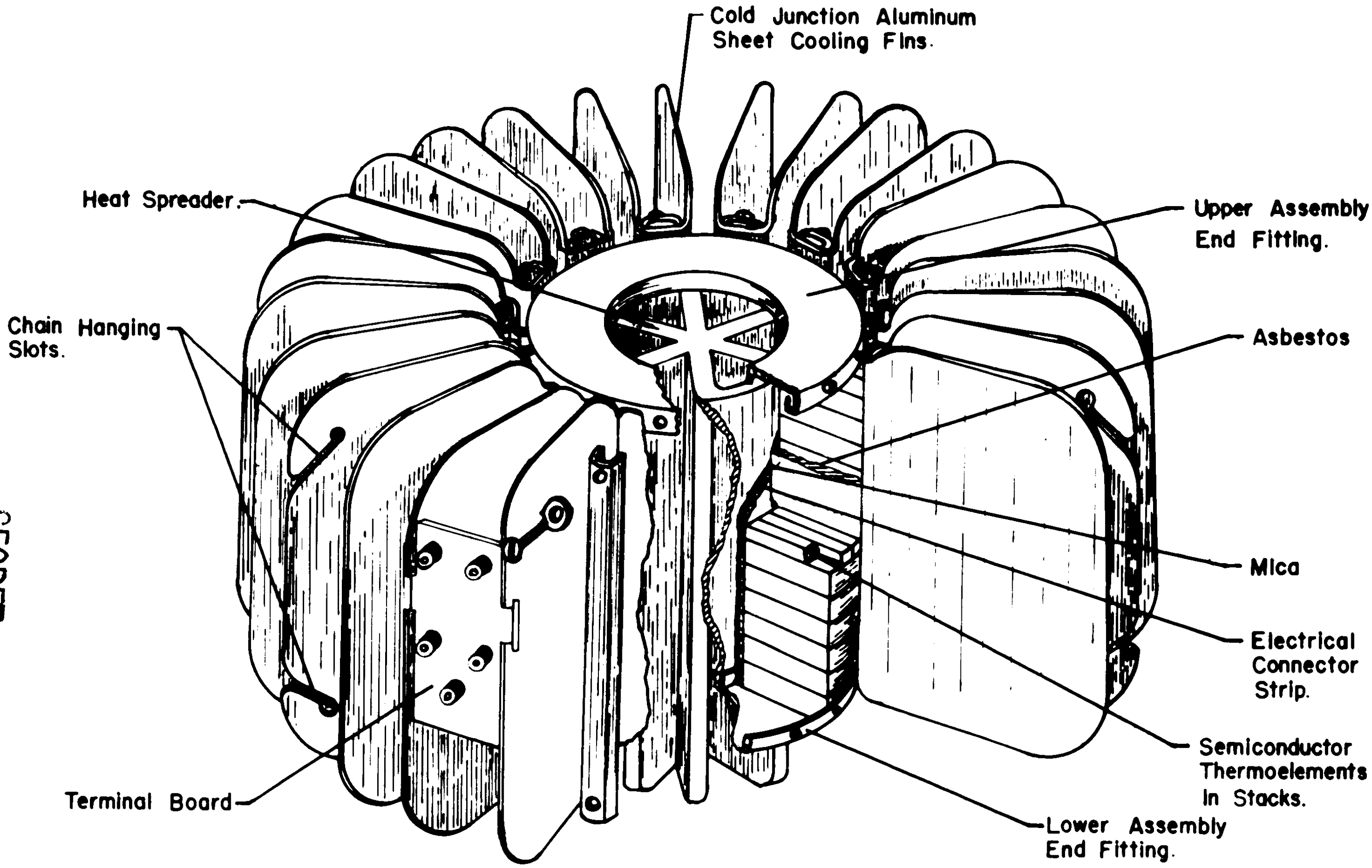

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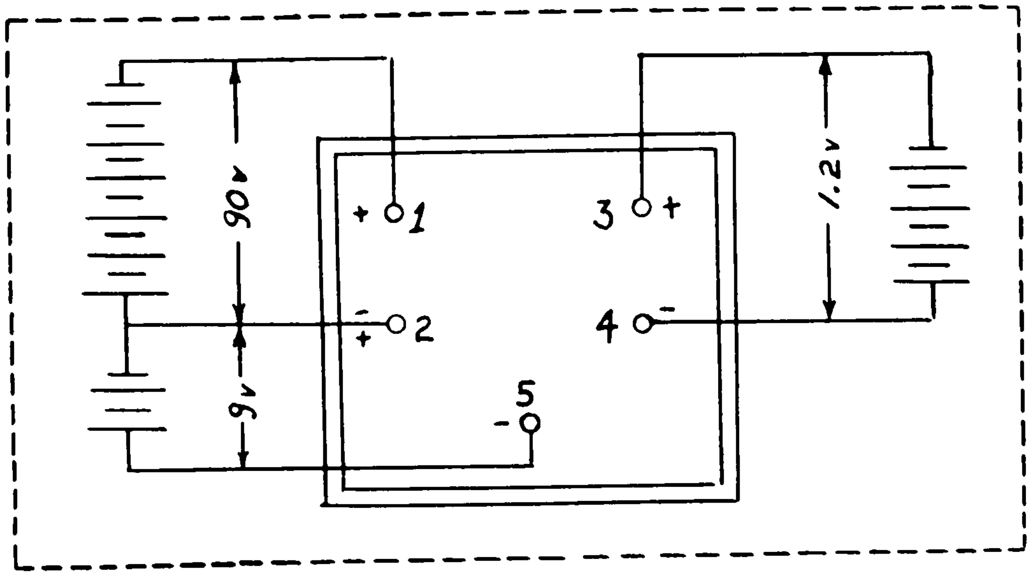
Cut Away Sketch
Exact internal structural details are Unknown.

FIG. 3

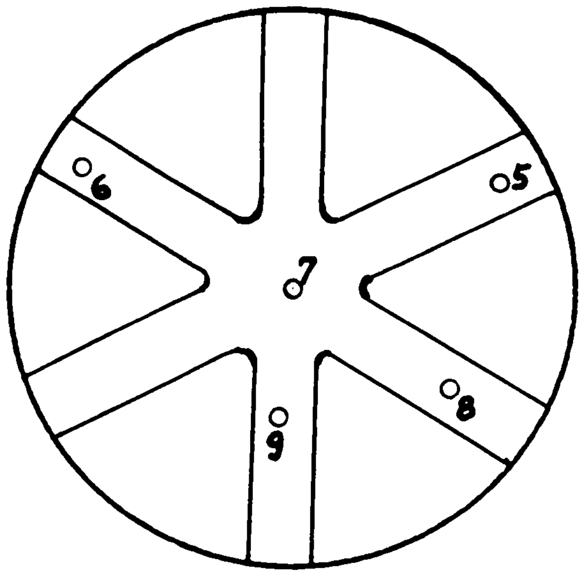


SCHEMATIC OF GENERATOR TERMINALS

Experimental loading of generator was made with the plate and bias supply in series--terminal No. 1 to terminal No. 5--giving nominally 99 volts (as recommended in the Instruction Booklet when the 9-volt bias is not separately required).

FIG. 4

25X1



TOP VIEW OF HOT ZONE

HEAT SPREADER

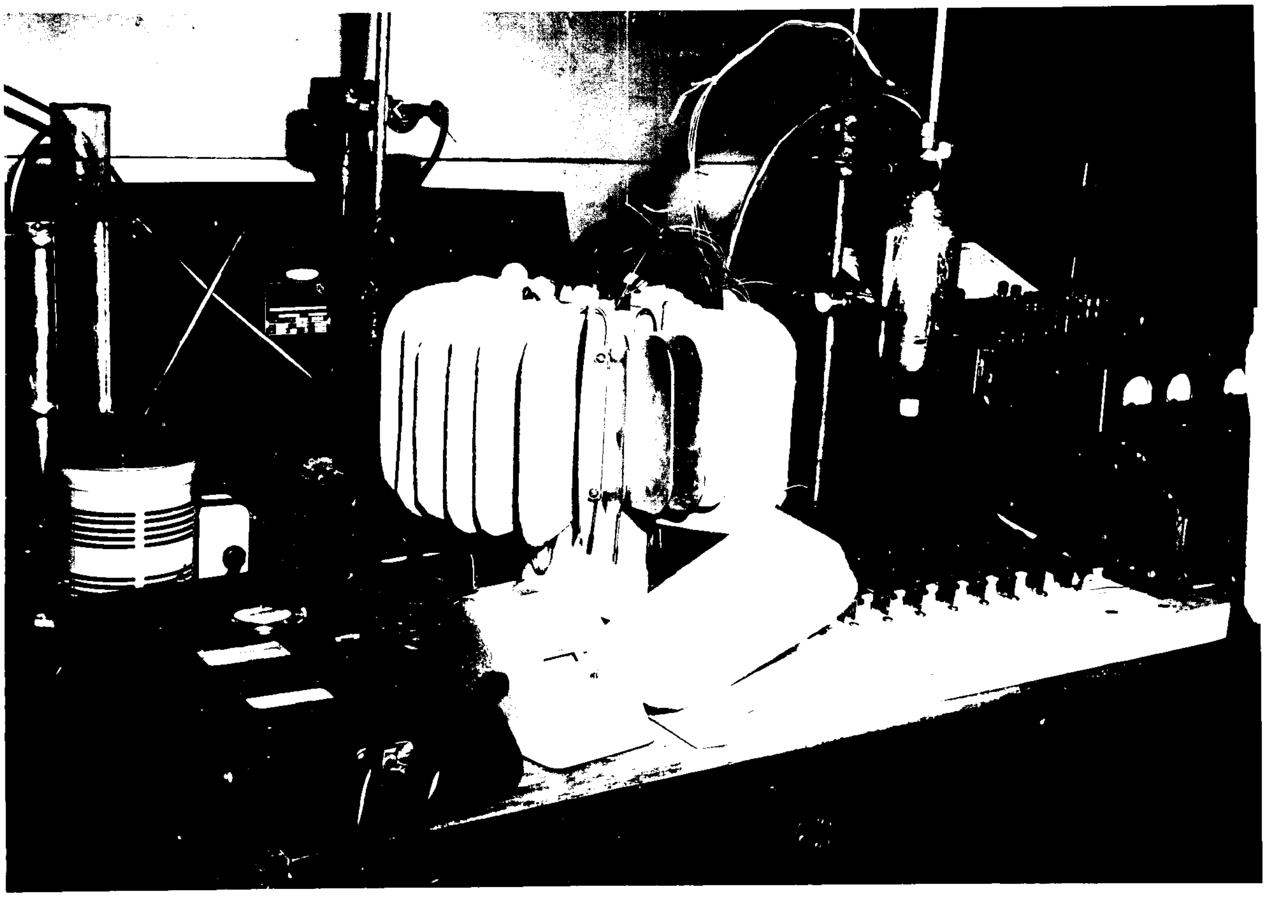
T3gK2-2

HOT ZONE MEASURING

Thermocouple Location

TC No.	Hole Depth
No. 5	1½ inches
6	1¼
7	½
8	1
9	1¼

FIG. 5



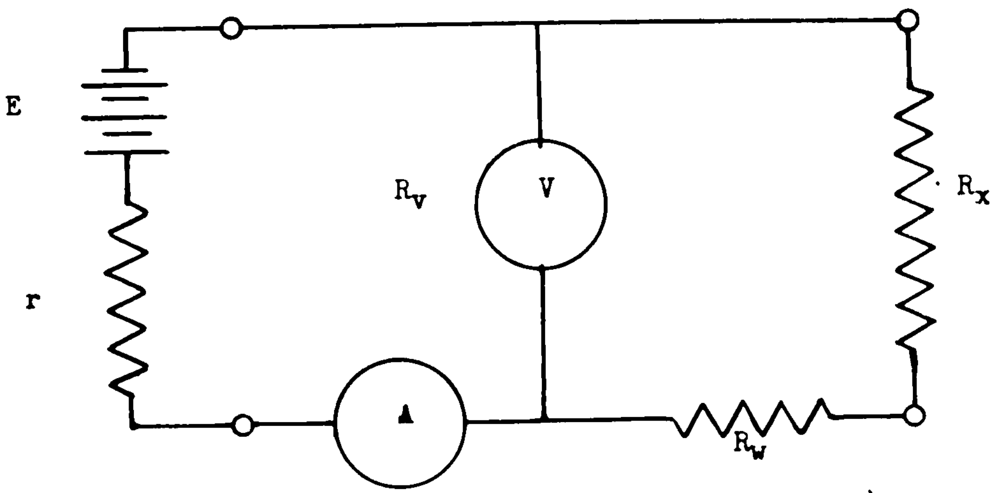
TEST SETUP

Cooling fin mittens removed from four fins to show arrangement of series-connected water-cooling tubes threaded through cold junction fin clamps

FIG. 6

25X1

GENERATOR AND LOADING CIRCUIT OF TEST SETUP



R_A (includes wiring resistance)

A. Plate Circuit

R_W is negligible

R_A is negligible

$I/V = 1/R_V + 1/R_x$

$V = E - Ir \quad \therefore \quad 1/R(\text{effective}) = I/V = 1/R_V + 1/R_x$

B. Filament Circuit

$I/V = 1/R_V + 1/(R_x + R_W)$

$V = E - I(r + R_A)$

FIG. 7

25X1

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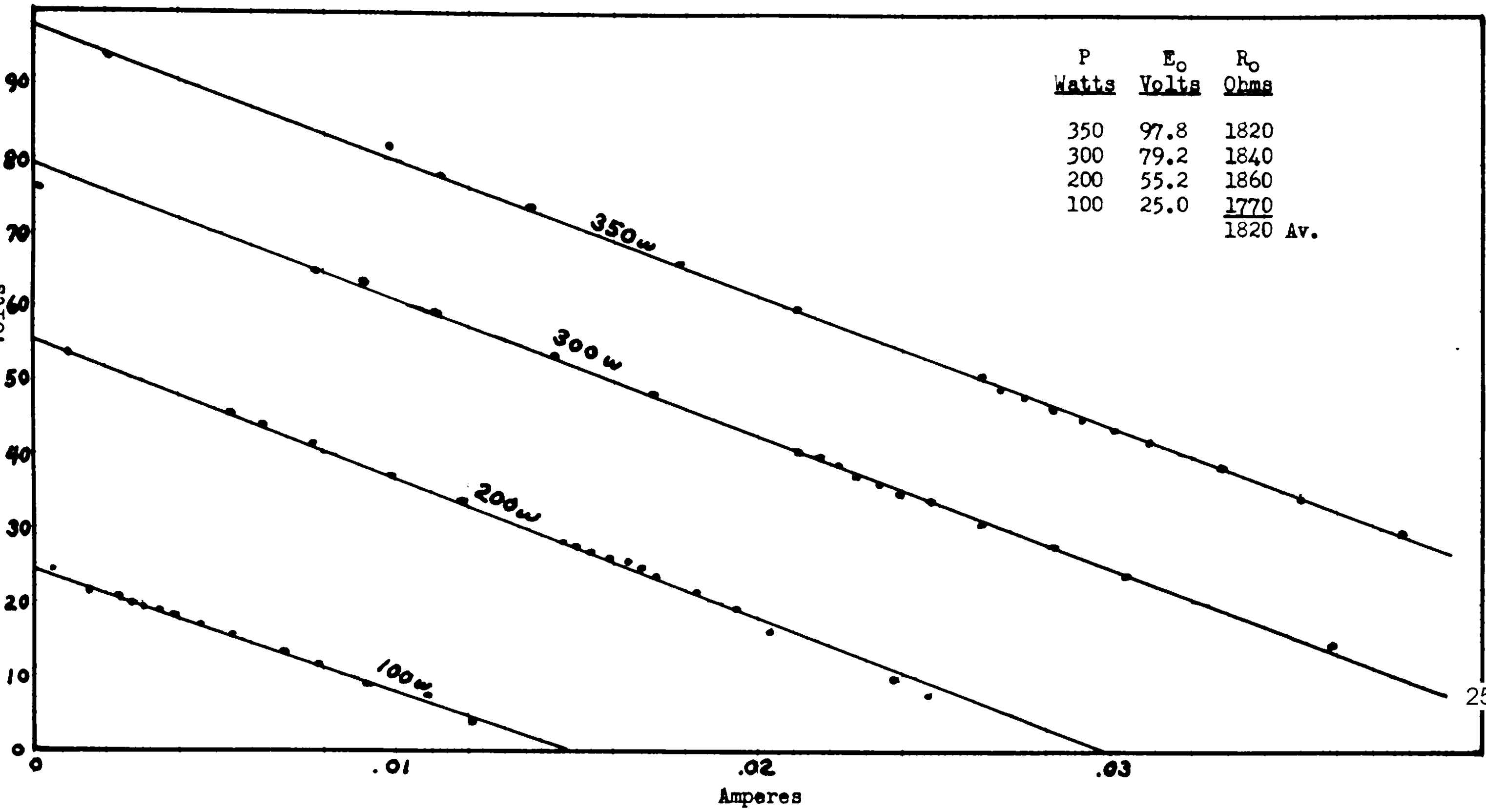
VOLTAGE-CURRENT CHARACTERISTIC OF B+ (WITH "C" SUPPLY IN SERIES) GENERATOR SUPPLY

AT SPECIFIED NOMINAL TOTAL INPUT "THERMAL" POWER



P Watts	E_o Volts	R_o Ohms
350	97.8	1820
300	79.2	1840
200	55.2	1860
100	25.0	1770
		1820 Av.

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25X1

FIG. 8a

VOLTAGE-CURRENT CHARACTERISTIC OF A-GENERATOR SUPPLY

AT SPECIFIED NOMINAL TOTAL INPUT "THERMAL" POWER

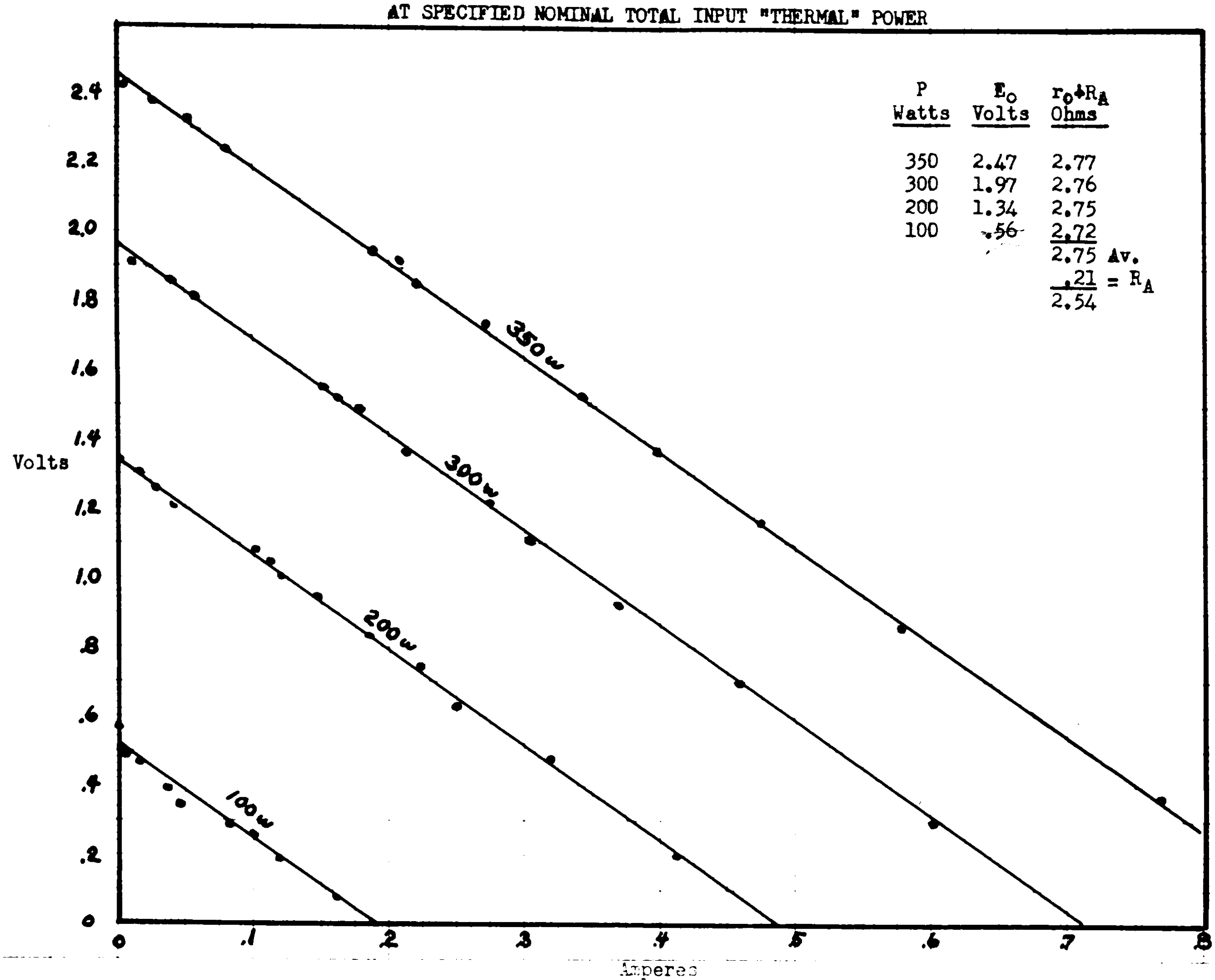

FIG. 8b

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B4 GENERATOR SUPPLY (WITH "C" SUPPLY IN SERIES)

P Watts	$\bar{a}(T_1-T_o)$ Volts	T_1-T_o $^oC.$	$\bar{a}$ Volts/$^oC.$	$\bar{a}$ Volts/$^oC.$
350	100.0	273	.366	.356
300	80.0	222.5	.360	.356
200	55.6	156	.356	.354
100	25.7	76.5	.336	.327

Average

r = 1850 ohms ± 30 ohms

$\bar{a}$ = 0.35 ± 0.015 volts/$^oC.$

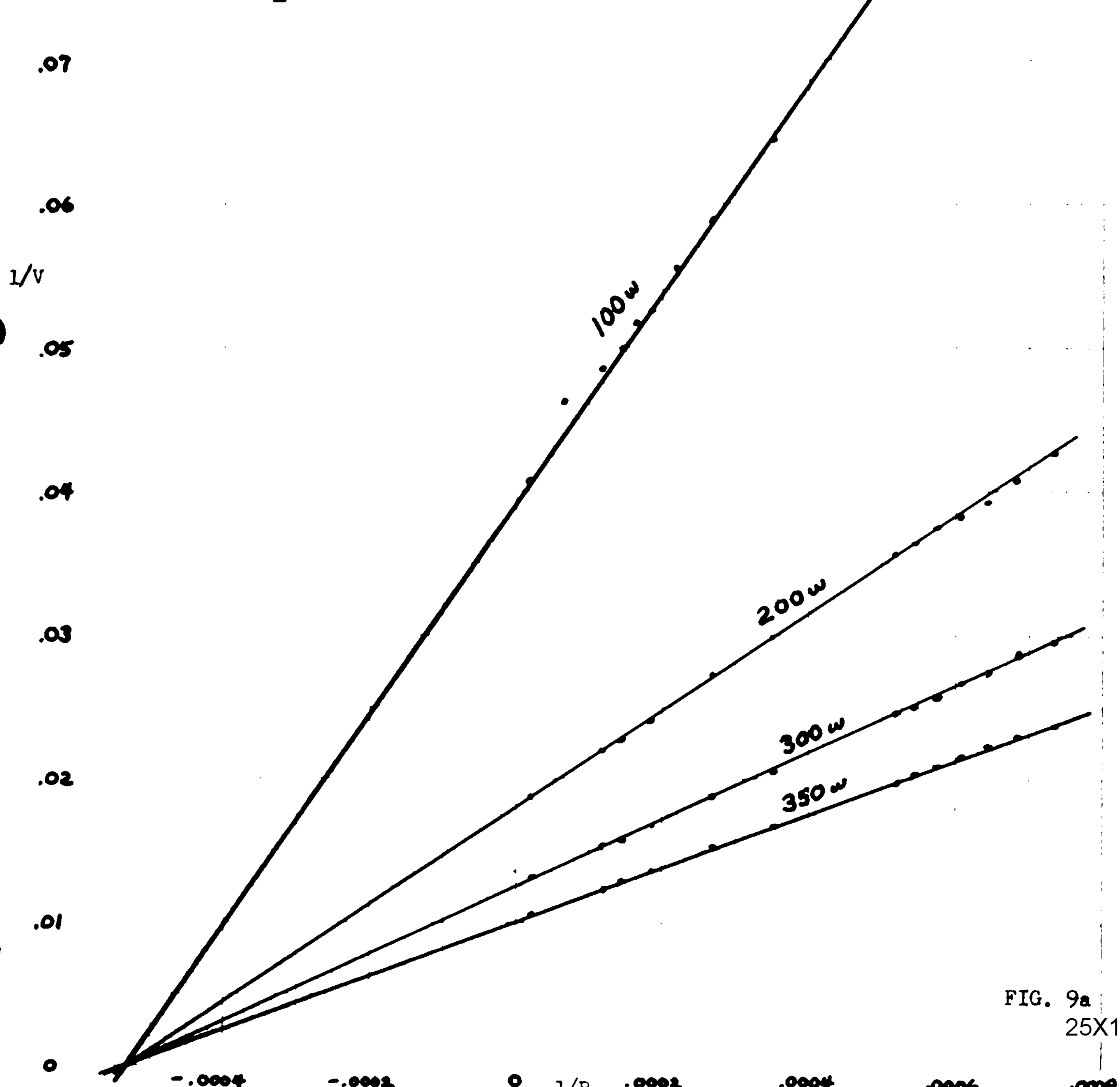
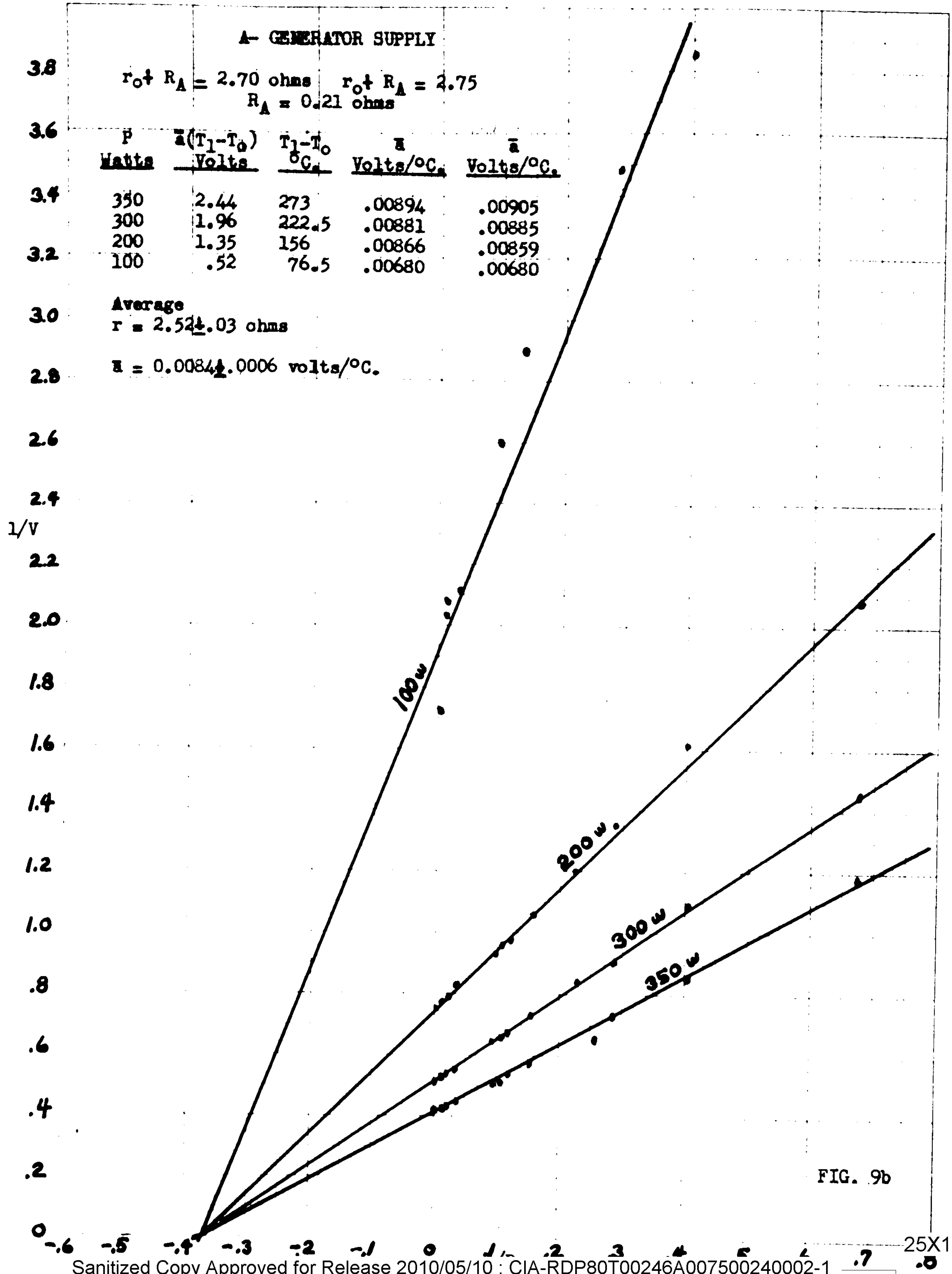


FIG. 9a



A- GENERATOR SUPPLY
$r_o + R_A$ = 2.70 ohms $r_o + R_A$ = 2.75
R_A = 0.21 ohms

P Watts	$\bar{a}(T_1-T_0)$ Volts	T_1-T_0 °C.	$\bar{a}$ Volts/°C.	$\bar{a}$ Volts/°C.
350	2.44	273	.00894	.00905
300	1.96	222.5	.00881	.00885
200	1.35	156	.00866	.00859
100	.52	76.5	.00680	.00680

Average
r = 2.52±.03 ohms
$\bar{a}$ = 0.0084±.0006 volts/°C.
1/V
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
-.6
-.5
-.4
-.3
-.2
-.1
0
.1
.2
.3
.4
.5
.6
.7
.8
100 w
200 w
300 w
350 w

FIG. 9b

25X1

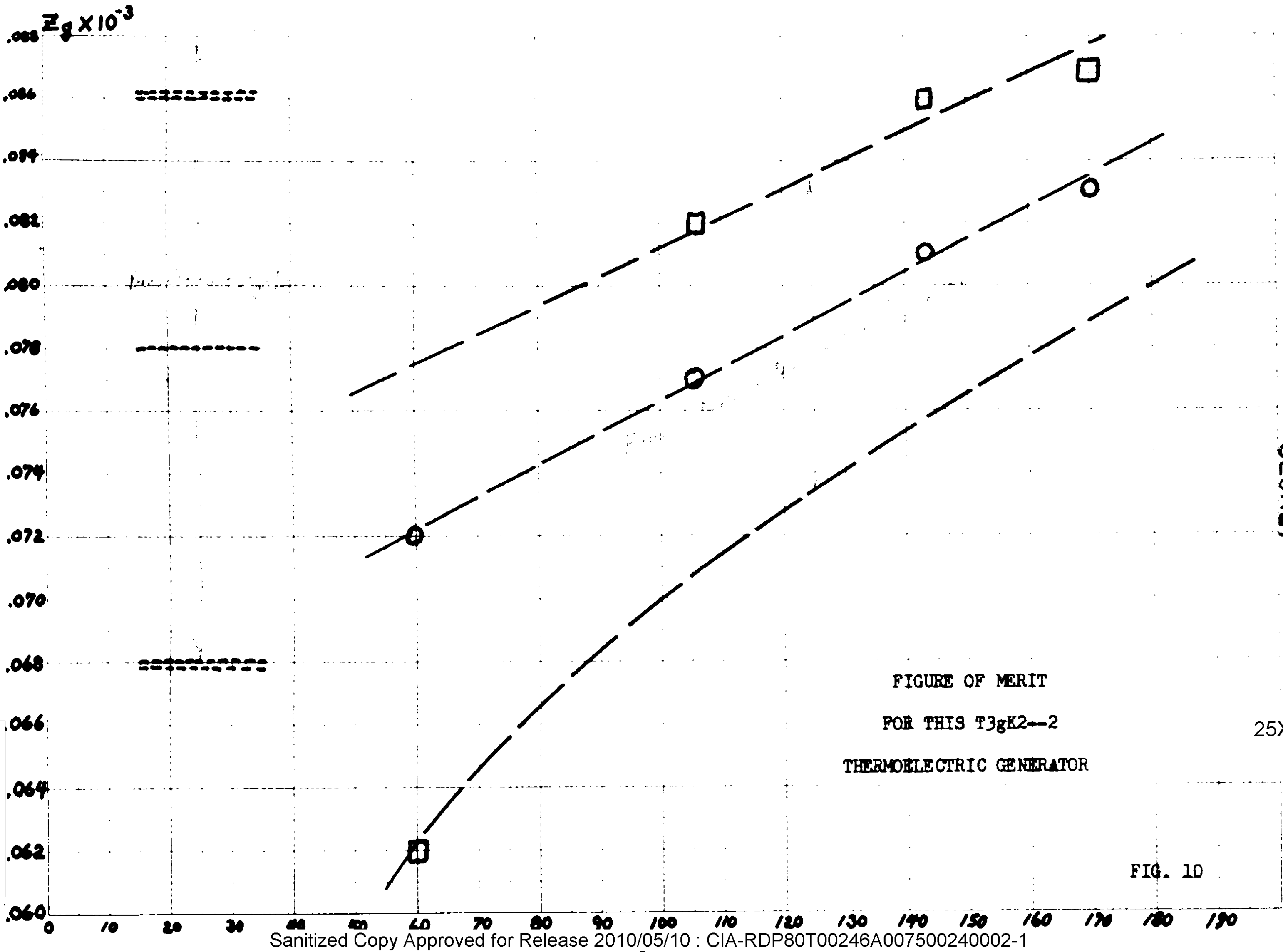


FIGURE OF MERIT

FOR THIS T3gK2--2

THERMOELECTRIC GENERATOR

FIG. 10